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Bibliometric Analysis on Optimal Path Planning for Robots

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Abstract

Traversing from a given point to another while avoiding collision with obstacles is one of the key goals of path planning for robots [1]. Doing so in the most optimal way - the minimum total distance traveled by the robot is the objective of our study [2,3]. To do so, the algorithms implemented on the robots need to constantly map the environment or workspace in real time and subsequently create paths for the traversal in the environment without colliding with objects or obstacles [4,5]. Throughout the years, many researchers have conducted their own studies, researches and have proposed approaches for the path planning in robotics [6]. This paper surveys these approaches and presents them to the reader. This paper performs a bibliometric analysis of the relevant publications published from 2016 to 2021. The result shows that 1117 literature pieces were published in 160 journals which shows the publication diversity. There has been an increasing interest in the topic over the past few years. This paper provides some useful insights into this topic so the researchers in this field can better recognize the relevant researches and potential research partners.

Keywords:

Path Planning, Optimal Path Planning, Autonomous Navigation, Motion Planning, Mobile Robots, Object Detection, Collision Avoidance, Path Planning Algorithms.

1. Introduction

Humans have for a long time been trying to create machines that can perform functions similar to themselves, to make their lives easier. The pursuit of such a creation has given existence to a branch of research and development of robots. One such robot in that massive domain is a path planning robot [2]. A path planning robot works on algorithms that allow it to navigate a particular area by itself from one point to another that may or may not be pre-defined for it.

Many algorithms have been developed and are being developed so as to create an algorithm that may allow a robot to optimally traverse in an area [6]. The research has progressed from a robot being able to move autonomously to being able to solve mazes and navigate areas by itself [7]. For solving a maze, the area and paths are set and the robot maps the whole area after traversing the maze at least once so as to categorize the maze according to whatever algorithm it is implemented with. In such a scenario, the algorithm has to only deal with tracking the maze and choosing the path with the minimum travel from the start location to the final [8]. An algorithm that may be the most optimal for such a scenario may not be so for an area containing dynamic obstacles or even static obstacles, which is the case with most of the areas where an autonomous navigation robot may be used [9,10]. A maze has a fixed area with fixed walls and unchanging landscape which makes it traversing the maze less complicated. However, for areas with static obstacles, the object will encounter the obstacle and would have to navigate around that obstacle according to the area that is being traversed. Algorithms such as A* and RTT can be used for such area traversal [6,11]. The major challenge arises when the robot has to traverse an area where dynamic obstacles are present. In such a scenario, only having information about the area to be traversed is inadequate [12]. With an ever changing landscape, the bot must be able to capture real time images of the environment and plan its path accordingly [13]. A prominent and heavily researched example of a path planning robot is self driving cars. Self driving cars implement this logic on a much more complex level as the variables that are involved can be very unpredictable [14]. A miniscule error can have major ramifications. The complexity of a path planning algorithm reduces as one moves from the ground towards the sky as the variables will reduce [15-18].

2. Literature Search and Discussion of Results

There are various methods for researching literature using publication records. These may be obtained through public portals, educational organization libraries or even independently. Various databases like Scopus, Science Direct, World of Science, ResearchGate etc. are very popular for accessing the research papers. Google Scholar is another popular website used for navigation to the desired paper or the papers of the given topic. The database that we have used for this study is Scopus. The search results were obtained from Scopus Records from the period 19th-21st May 2021. In this paper, the results of the search from this period are used for the review.

2.1 Search established from Keywords

The most frequently used method for searching the literature is on the basis of keyword-search. Here, the main keywords are “Path Planning for Robots”, limiting the search to years 2016, 2017, 2018, 2019, 2020 and 2021. The results were also limited to All Open Access.

The exact query string that we used was “KEY (path AND planning AND for AND robots) AND (LIMIT-TO (OA,"all")) AND (LIMIT-TO (PUBYEAR,2021) OR LIMIT-TO (PUBYEAR,2020) OR LIMIT-TO (PUBYEAR,2019) OR LIMIT-TO (PUBYEAR,2018) OR LIMIT-TO (PUBYEAR,2017) OR LIMIT-TO (PUBYEAR,2016))”.

Table 1 gives the list of the top 10 keywords connected to the main keywords.

Table 1: List of top 10 keywords

Keywords	No. of Contributions
Robot Programming	779
Motion Planning	724
Path Planning	443
Robots	382
Robotics	238
Mobile Robots	225
Motion and Path Planning	155
Agricultural Robots	144
Collision Avoidance	127
Navigation	127

Source: Scopus Database (accessed on 19th-21st May'21)

We have restricted the results to the Contributions made in the English Language only. From the 1117 obtained results, 1102 contributions are in English language. Table 2 gives the contributions in various languages.

Table 2: Contribution Languages

Languages	No. of Contribution
English	1102
Chinese	7
Japanese	2
Korean	2
Russian	2
Spanish	2
Total	1117

Source: Scopus Database (accessed on 19th-21st May'21)

Many different types of research contributions are published on Path Planning for Robots. Most of the contributions are in the form of articles published in journals and conference proceedings. Journal articles comprise 69.02% and conference papers comprise 28.73% of the total contributions. Table 3 shows the types of contributions.

Table 3: Types of Contributions

Contribution Type	No. of Contributions	Percentage
Journal articles	771	69.02%
Conference Papers	321	28.73%
Review	17	1.52%
Book Chapter	5	0.44%
Editorial	2	0.17%
Letter	1	0.08%

Source: Scopus Database (accessed on 19th-21st May'21)

2.2 Key inferences from the Initial Data

Here, we performed a literature survey based on keyword-search from the Scopus records that gave us 1117 unique results. As per these results, 301 publications were published in 2020, the highest number in the 5 year period. Figure 1 shows the yearly number of contributions from the period 2012 to 2021 with the period 2016-2021 highlighted.

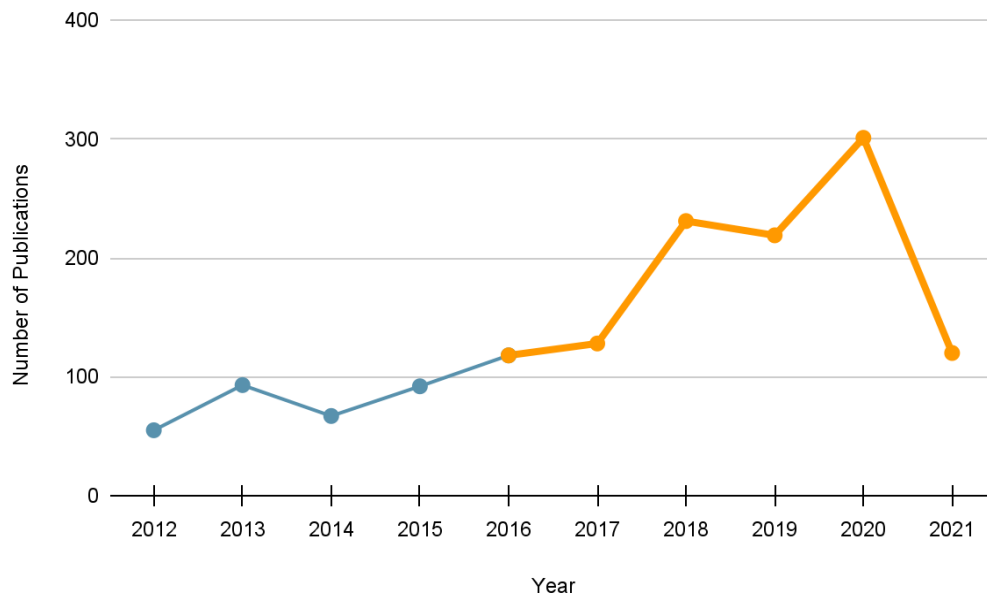


Figure 1: Yearly number of contributions from 2012 to 2021.

Source: Scopus Database (accessed on 19th-21st May'21)

Table 4 gives the number of contributions made each year.

Table 4: No. of Contributions every year

Year of Publication	No. of Contributions
2021*	120
2020	301
2019	219
2018	231
2017	128
2016	118
Sub-Total	1117
2015	92
2014	67
2013	93
2012	55
Total	1424

* : as of 21st May 2021

Source: Scopus Database (accessed on 19th-21st May'21)

Since 2018, a rise in the number of contributions is seen. This can partly be ascribed to the commercialization of Boston Dynamics robots and Microsoft officially announcing the ROS Platform to be officially supported by Microsoft Windows.

3. Bibliometric Research

In the following segment, we carried out bibliometric research in terms of availability of literature, uniqueness, subject areas, its authors and their affiliations, various geographical locations, sources of funding, citations and other pertinent factors and statistics.

3.1 Analysis based on Geographical Locations

Authors from 77 different countries have contributed in the area of path planning in robotics. China, United States, United Kingdom, Germany and India are the 5 countries with the most amount of contributions. Figure 2 gives the geographical heat map of path planning in robotics research as regards to the number of contributions.

Geographical Heat Map

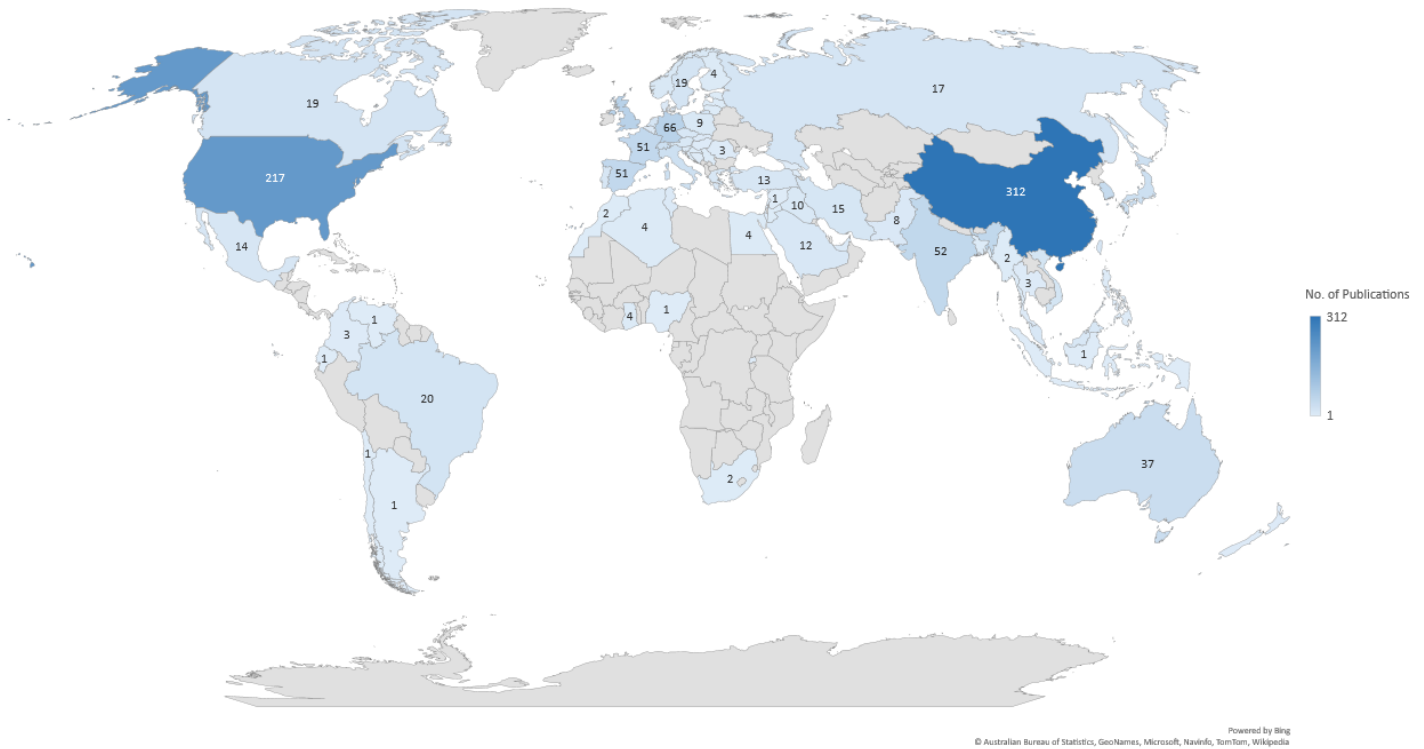


Figure 2: Geographical Heat Map of the Review of Path Planning in Robotics
Source: Scopus Database (access on 19th-21st May'21)

Figure 3 shows the country-wise number of publications.

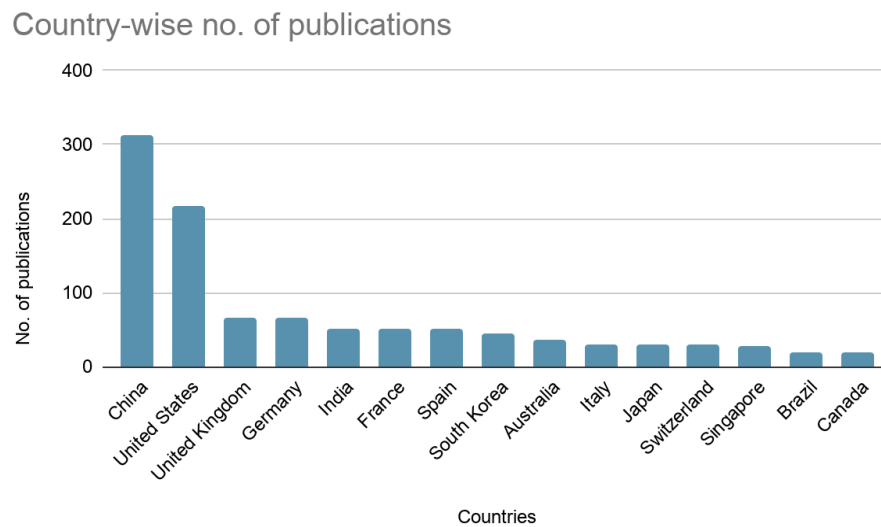


Figure 3: Country-wise number of publications
Source: Scopus Database (access on 19th-21st May'21)

3.2 Research on the basis of Field of Study

Figure 4 gives the research of publications based on the field of study. Computer Science is the subject area with the maximum number of research papers, followed closely by Engineering with 32.3% and 32.2% of all literatures respectively. The research area majorly involves algorithm development, hence, subject areas like Computer Science, Engineering and Mathematics are highly popular whereas subject areas like Business, Management, Psychology and Economics are less popular.

Publications by Field of Study

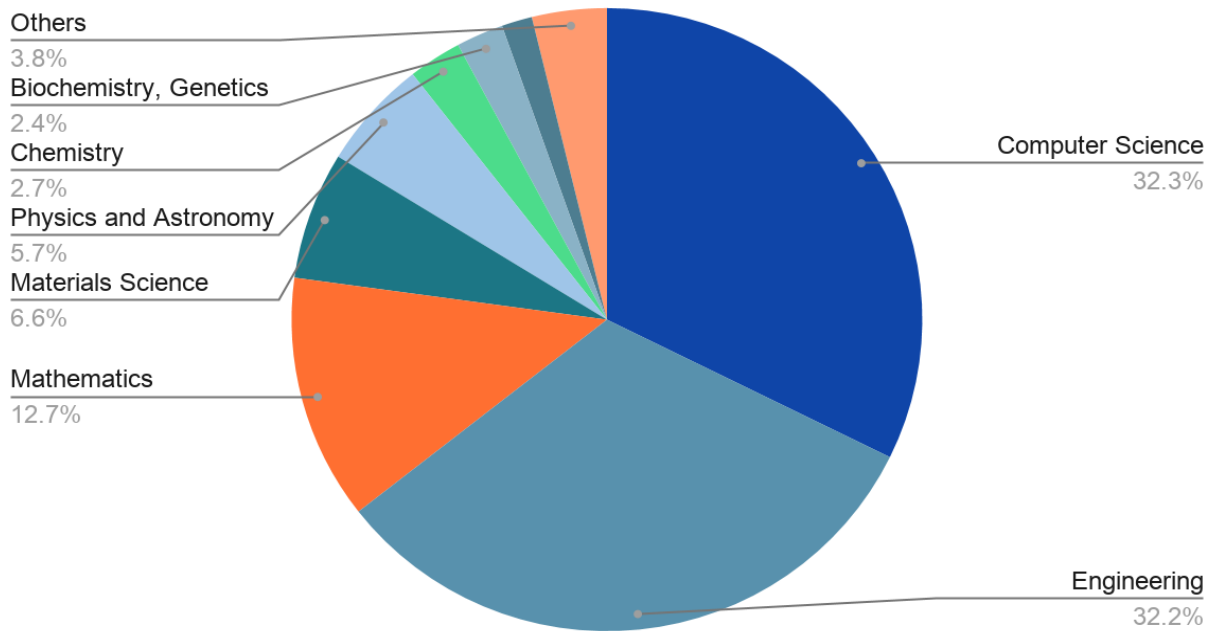


Figure 4: Research of Publications on the basis of Field of Study
Source: Scopus Database (access on 19th-21st May'21)

3.3 Research on the basis of Affiliations

Figure 5 gives the top 5 institutes and universities with the most contributions in Path Planning in Robotics. The research in this area is dominated by the Ministry of Education China, Beihang University and Chinese Academy of Sciences.

No. of Publications based on Affiliations

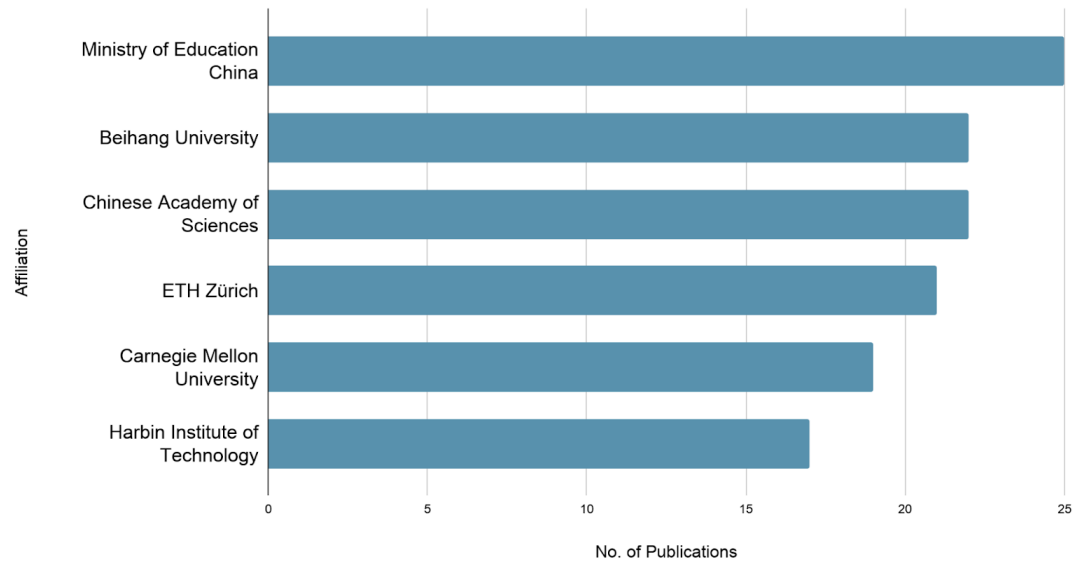


Figure 5: Research of Publications on the basis of Affiliations

Source: Scopus Database (access on 19th-21st May'21)

3.4 Research on the basis of Publication by Authors

Figure 6 gives the record of the most relevant contributors in the field of Path Planning in Robotics. Le, A.V. is the most contributing author with 9 contributions followed by Elara, M.R., Hutter, M., Mohan, R.E. and Yu, J. with 8 contributions each.

No. of Publications by Author

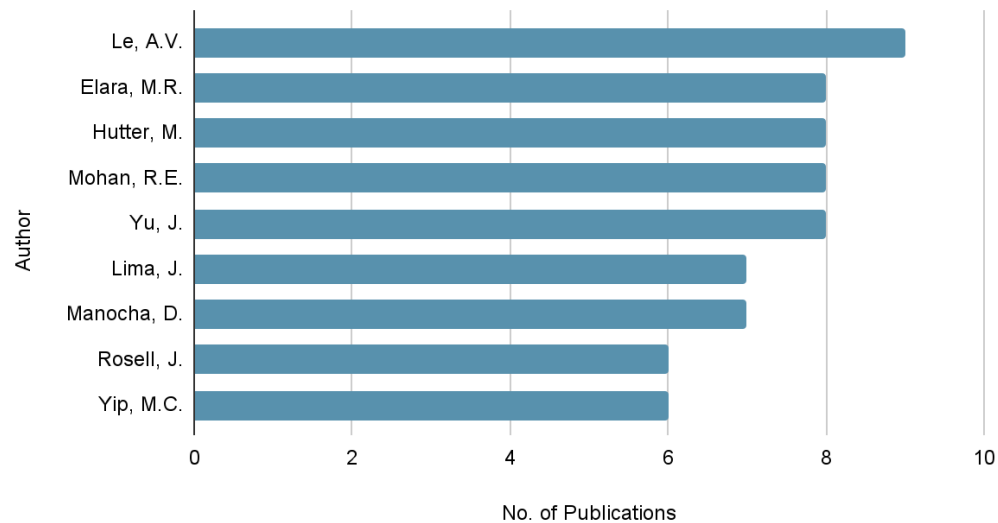


Figure 6: Contributing Authors in Path Planning in Robotics

Source: Scopus Database (access on 19th-21st May'21)

3.5 Research on the basis of Source of Publication

Figure 7 gives the contributions based on the type of document. 69.0% of the total contributions are in the form of Journal Articles. It is also observed that 28.7% of all the publications are in the form of Conference Papers. The other notable types of publications are Review papers, book chapters, letters and editorials.

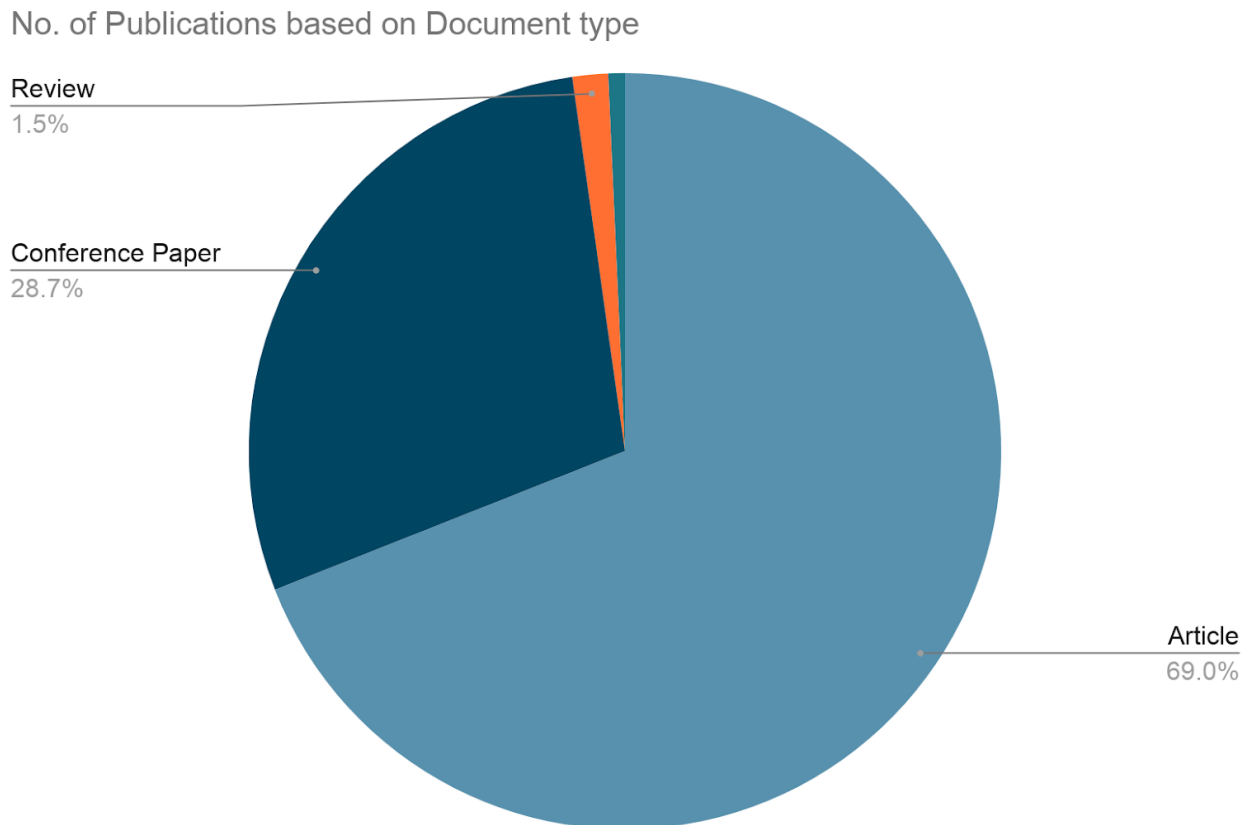


Figure 7: Research of Publications based on Type of Publication
Source: Scopus Database (access on 19th-21st May'21)

3.6 Research on the basis of Publications and Sources of Funding

Figure 8 gives the review of the sources of funding and publication statistics. National Natural Science Foundation of China is the organisation with the highest number of contributions. The National Science Foundation follows the Natural Science Foundation of China with roughly half the number of contributions.

Publications on the basis of Sources of Funding

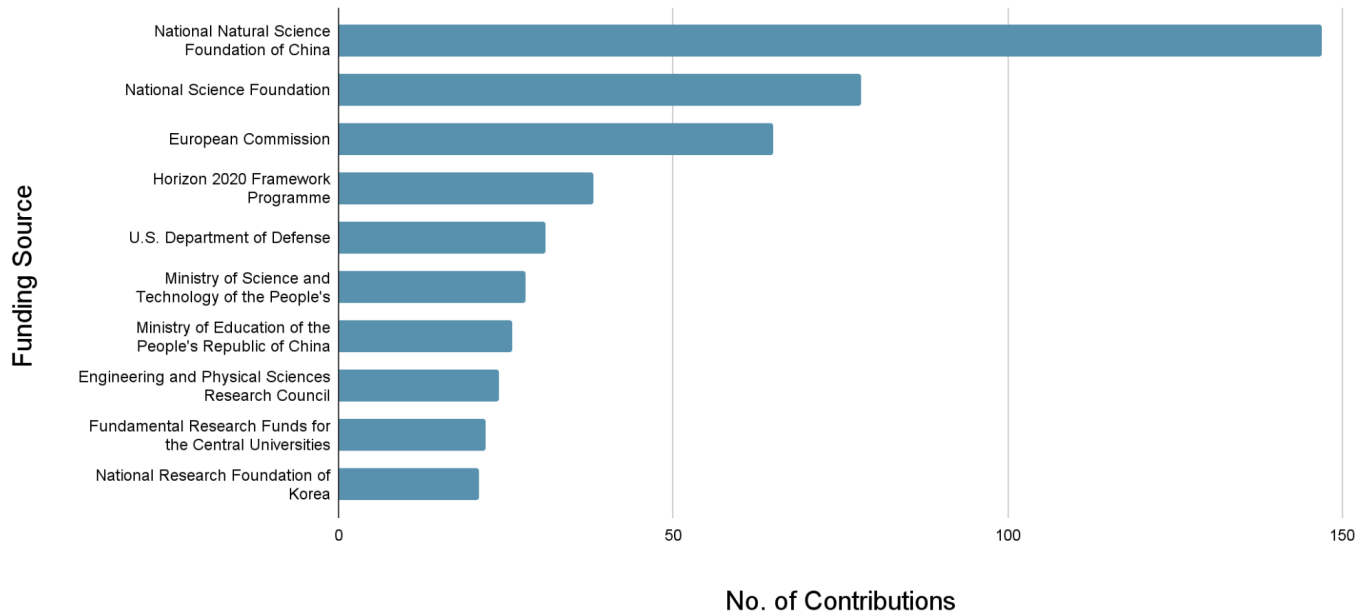


Figure 8: Research of Contributions on the basis of Sources of Funding
Source: Scopus Database (access on 19th-21st May'21)

3.7 Research on the basis of Citation Statistics

Table 5 gives the research of publications based on their citations from the period 2012 to 2021. We have considered the period from 2016 to 2021 for the citation data, the year it was published, title of the article and the contributors. The paper titled “A survey on coverage path planning for robotics” by “Galceran, E., Carreras, M.” received the most number of citations with 592 citations.

Table 5: Year-wise Citations Analysis for the Publications

Publication Year	Publication Title	Authors	Year						Total
			<2016	2017	2018	2019	2020	2021	
2012	Persistent robotic tasks: Monitoring and sweeping in changing environments	Smith, S.L., Schwager, M., Rus, D.	83	11	16	22	12	5	149
2013	A survey on coverage path planning for robotics	Galceran, E., Carreras, M.	99	64	109	144	149	27	592

2014	Sampling-based robot motion planning: A review	Elbanhawi, M., Simic, M.	34	24	59	73	79	26	295
2015	Algorithms for collision-free navigation of mobile robots in complex cluttered environments: A survey	Hoy, M., Matveev, A.S., Savkin, A.V.	23	28	67	63	56	11	248
2016	Sensor Planning for a Symbiotic UAV and UGV System for Precision Agriculture	Tokekar, P., Hook, J.V., Mulla, D., Isler, V.	-	11	27	51	60	24	173
2017	A hierarchical global path planning approach for mobile robots based on multi-objective particle swarm optimization	Mac, T.T., Copot, C., Tran, D.T., Keyser, R.D.	-	-	17	30	36	15	98
2018	Gait and Trajectory Optimization for Legged Systems Through Phase-Based End-Effector Parameterization	Winkler, A.W., Bellicoso, C.D., Hutter, M., Buchli, J.	-	-	7	27	45	9	88
2019	A review: On path planning strategies for navigation of mobile robot	Patle, B.K., Babu L, G., Pandey, A., Parhi, D.R.K., Jagadeesh, A.	1	-	-	4	50	25	80
2020	Multi-objective path planning of an autonomous mobile robot using hybrid PSO-MFB optimization algorithm	Ajeil, F.H., Ibraheem, I.K., Sahib, M.A., Humaidi, A.J.	-	-	-	-	13	12	25
2021	Hexapod robot gait switching for energy consumption and cost of transport management using heuristic algorithms	Luneckas, M., Luneckas, T., Kriauciūnas, J., Udris, D., Plonis, D., Damaševičius, R., Maskeliūnas, R.	-	-	-	-	-	3	3

Source: Scopus Database (accessed on 19th to 21st May 2021)

Table 6 shows the list of top 10 most cited publications from the period 2016 to 2021.

Table 6: Most cited publications from the period 2016 to 2021.

Publication Year	Publication Title	Authors	No. of citations
2016	Sensor Planning for a Symbiotic UAV and UGV System for Precision Agriculture	Tokekar, P., Hook, J.V., Mulla, D., Isler, V.	173
2016	Survey of Robot 3D Path Planning Algorithms	Yang, L., Qi, J., Song, D., Xiao, J., Han, J., Xia, Y.	108
2017	A hierarchical global path planning approach for mobile robots based on multi-objective particle swarm optimization	Mac, T.T., Copot, C., Tran, D.T., Keyser, R.D.	98
2016	Optimal Multirobot Path Planning on Graphs: Complete Algorithms and Effective Heuristics	Yu, J., LaValle, S.M.	93
2017	Planning dynamically feasible trajectories for quadrotors using safe flight corridors in 3-D complex environments	Liu, S., Watterson, M., Mohta, K., Sun, K., Bhattacharya, S., Taylor, C.J., Kumar, V.	90
2018	Gait and Trajectory Optimization for Legged Systems Through Phase-Based End-Effector Parameterization	Winkler, A.W., Bellicoso, C.D., Hutter, M., Buchli, J.	88
2017	Enhanced discrete particle swarm optimization path planning for UAV vision-based surface inspection	Phung, M.D., Quach, C.H., Dinh, T.H., Ha, Q.	82
2019	A review: On path planning strategies for navigation of mobile bot	Patle, B.K., Babu L, G., Pandey, A., Parhi, D.R.K., Jagadeesh, A.	80
2018	Genetic algorithm based approach for autonomous mobile robot path planing	Lamini, C., Benhlina, S., Elbekri, A.	73
2018	Path smoothing techniques in robot navigation: State-of-the-art, current and future challenges	Ravankar, A., Ravankar, A.A., Kobayashi, Y., Hoshino, Y., Peng, C.-C.	65

Source: Scopus Database (accessed on 19th to 21st May 2021)

3.8 Research on the basis of Publication Source

Figure 9 gives yearly statistics regarding sources of publications. IEEE Robotics and Automation Letters had the most contributions for the period followed by IEEE Access & International Journal of Advanced Robotic Systems (IJARS) with 165, 100 and 76 publications respectively.

Year-wise Publications by Publication Source

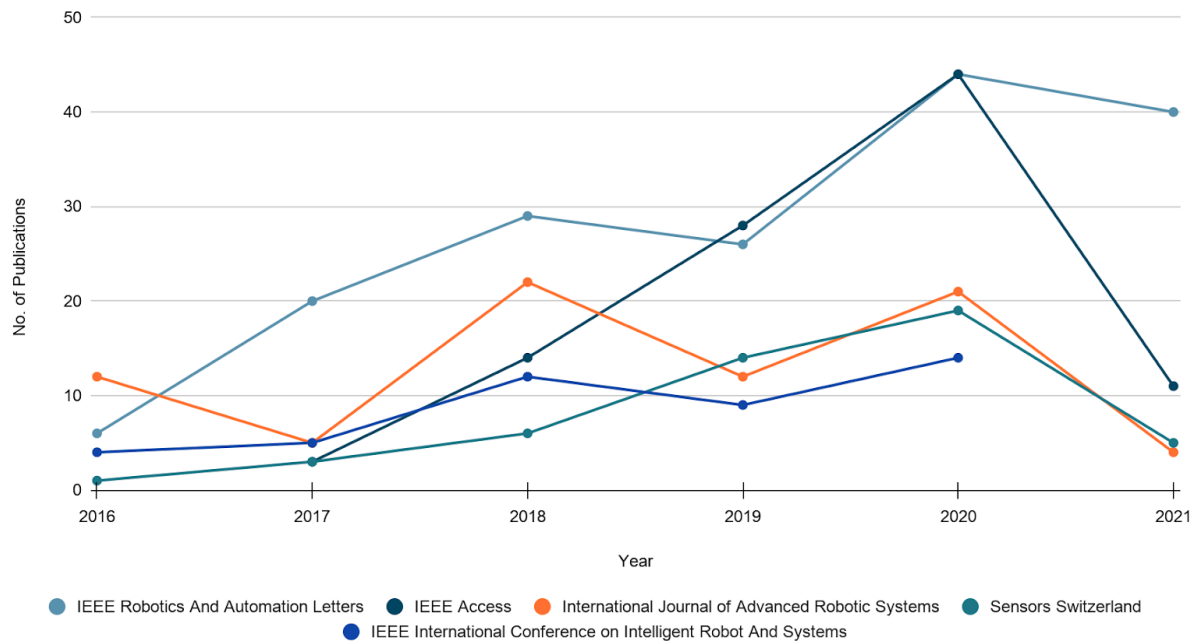


Figure 9: Year-wise Publications by Publication Source
Source: Scopus Database (accessed on 19th-21st May'21)

4 Limitations of Bibliometric Analysis

The bibliometric analysis is a method of searching for relevant contributions in the form of literature from a given database based on keywords. This paper extracted the literature from Scopus because it is amongst the largest databases available through Symbiosis International University library.

5 Conclusion

In this paper, bibliometric research on Path Planning in Robotics is performed on the basis of the data acquired from the Scopus Records during the period 19th-21st May 2021. China, United States, UK, Germany & India are the top 5 countries with the most amount of contributions. Publications from Engineering, Mathematics and Computer Science, contribute around 77% of the total publications in Path Planning in Robotics. National Natural Science Foundation of China is the leading source of funding for research in this area. Most Publications are affiliated to Ministry of Education China. Bibliometric research reflects that most of the publications are in the form of conference proceedings and journal articles (97.7%). Most of the research papers are published in IEEE Robotics And Automation Letters followed by IEEE Access and IJARS.

REFERENCES

- [1] Gilbert, E. G., & Johnson, D. W. (1985). Distance functions and their application to robot path planning in the presence of obstacles. *IEEE Journal on Robotics and Automation*, 1(1), 21-30. doi:10.1109/JRA.1985.1087003
- [2] Alexopoulos, C., & Griffin, P. M. (1992). Path planning for a mobile robot. *IEEE Transactions on Systems, Man and Cybernetics*, 22(2), 318-322. doi:10.1109/21.148404
- [3] Yang, L., Qi, J., Song, D., Xiao, J., Han, J., & Xia, Y. (2016). Survey of robot 3D path planning algorithms. *Journal of Control Science and Engineering*, 2016 doi:10.1155/2016/7426913
- [4] Patle, B. K., Babu L, G., Pandey, A., Parhi, D. R. K., & Jagadeesh, A. (2019). A review: On path planning strategies for navigation of mobile robot. *Defence Technology*, 15(4), 582-606. doi:10.1016/j.dt.2019.04.011
- [5] Dai, X., Long, S., Zhang, Z., & Gong, D. (2019). Mobile robot path planning based on ant colony algorithm with a* heuristic method. *Frontiers in Neurorobotics*, 13 doi:10.3389/fnbot.2019.00015
- [6] Iram Noreen, Amna Khan and Zulfikar Habib, "Optimal Path Planning using RRT* based Approaches: A Survey and Future Directions" *International Journal of Advanced Computer Science and Applications(IJACSA)*, 7(11), 2016 doi:10.14569/IJACSA.2016.071114
- [7] Hoy, M., Matveev, A. S., & Savkin, A. V. (2015). Algorithms for collision-free navigation of mobile robots in complex cluttered environments: A survey. *Robotica*, 33(3), 463-497. doi:10.1017/S0263574714000289
- [8] Galceran, E., & Carreras, M. (2013). A survey on coverage path planning for robotics. *Robotics and Autonomous Systems*, 61(12), 1258-1276. doi:10.1016/j.robot.2013.09.004
- [9] Ajeil, F. H., Ibraheem, I. K., Sahib, M. A., & Humaidi, A. J. (2020). Multi-objective path planning of an autonomous mobile robot using hybrid PSO-MFB optimization algorithm. *Applied Soft Computing Journal*, 89 doi:10.1016/j.asoc.2020.106076
- [10] Yu, J., & LaValle, S. M. (2016). Optimal multirobot path planning on graphs: Complete algorithms and effective heuristics. *IEEE Transactions on Robotics*, 32(5), 1163-1177. doi:10.1109/TRO.2016.2593448
- [11] Sa, X., Huaiyu, W., & Zhihuan, C. (2020). Research of mobile robot path planning based on improved A* algorithm. Paper presented at the Proceedings - 2020 Chinese Automation Congress, CAC 2020, 7619-7623. doi:10.1109/CAC51589.2020.9327676
- [12] Smith, S. L., Schwager, M., & Rus, D. (2012). Persistent robotic tasks: Monitoring and sweeping in changing environments. *IEEE Transactions on Robotics*, 28(2), 410-426. doi:10.1109/TRO.2011.2174493
- [13] Mac, T. T., Copot, C., Tran, D. T., & Keyser, R. D. (2017). A hierarchical global path planning approach for mobile robots based on multi-objective particle swarm optimization. *Applied Soft Computing Journal*, 59, 68-76. doi:10.1016/j.asoc.2017.05.012

- [14] Lamini, C., Benhlima, S., & Elbekri, A. (2018). Genetic algorithm based approach for autonomous mobile robot path planning. Paper presented at the Procedia Computer Science, , 127 180-189. doi:10.1016/j.procs.2018.01.113
- [15] Luneckas, M., Luneckas, T., Kriaučiūnas, J., Udris, D., Plonis, D., Damaševičius, R., & Maskeliūnas, R. (2021). Hexapod robot gait switching for energy consumption and cost of transport management using heuristic algorithms. *Applied Sciences (Switzerland)*, 11(3), 1-13. doi:10.3390/app11031339
- [16] Song, R., Liu, Y., & Bucknall, R. (2019). Smoothed A* algorithm for practical unmanned surface vehicle path planning. *Applied Ocean Research*, 83, 9-20. doi:10.1016/j.apor.2018.12.001
- [17] Liu, S., Watterson, M., Mohta, K., Sun, K., Bhattacharya, S., Taylor, C. J., & Kumar, V. (2017). Planning dynamically feasible trajectories for quadrotors using safe flight corridors in 3-D complex environments. *IEEE Robotics and Automation Letters*, 2(3), 1688-1695. doi:10.1109/LRA.2017.2663526
- [18] Phung, M. D., Quach, C. H., Dinh, T. H., & Ha, Q. (2017). Enhanced discrete particle swarm optimization path planning for UAV vision-based surface inspection. *Automation in Construction*, 81, 25-33. doi:10.1016/j.autcon.2017.04.013
- [19] Patle, B. K., Babu L, G., Pandey, A., Parhi, D. R. K., & Jagadeesh, A. (2019). A review: On path planning strategies for navigation of mobile robot. *Defence Technology*, 15(4), 582-606. doi:10.1016/j.dt.2019.04.011
- [20] Dai, X., Long, S., Zhang, Z., & Gong, D. (2019). Mobile robot path planning based on ant colony algorithm with a* heuristic method. *Frontiers in Neurorobotics*, 13 doi:10.3389/fnbot.2019.00015
- [21] Zhang, H., Lin, W., & Chen, A. (2018). Path Planning for the Mobile Robot: A Review. *Symmetry*, 10(10), 450 doi:10.3390/sym10100450
- [22] Winkler, A. W., Bellicoso, C. D., Hutter, M., & Buchli, J. (2018). Gait and trajectory optimization for legged systems through phase-based end-effector parameterization. *IEEE Robotics and Automation Letters*, 3(3), 1560-1567. doi:10.1109/LRA.2018.2798285
- [23] Ravankar, A., Ravankar, A. A., Kobayashi, Y., Hoshino, Y., & Peng, C. -. (2018). Path smoothing techniques in robot navigation: State-of-the-art, current and future challenges. *Sensors (Switzerland)*, 18(9) doi:10.3390/s18093170
- [24] Le, A. V., Prabakaran, V., Sivanantham, V., & Mohan, R. E. (2018). Modified a-star algorithm for efficient coverage path planning in tetris inspired self-reconfigurable robot with integrated laser sensor. *Sensors (Switzerland)*, 18(8) doi:10.3390/s18082585
- [25] Tokekar, P., Hook, J. V., Mulla, D., & Isler, V. (2016). Sensor planning for a symbiotic UAV and UGV system for precision agriculture. *IEEE Transactions on Robotics*, 32(6), 1498-1511. doi:10.1109/TRO.2016.2603528
- [26] Elbanhawi, M., & Simic, M. (2014). Sampling-based robot motion planning: A review. *IEEE Access*, 2, 56-77. doi:10.1109/ACCESS.2014.2302442